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GENERAL INFORMATION SHEET ON DEHYDRATION OF VEGETABLES

The Dehydration Committee
U.S.Bureau of Agricultural Chemistry and Engineering
U. S. Department of Agriculture

There are a number of factors which should be considered in the dehydration of vegetables in order to make a dried product which, when rehydrated, will closely resemble the original fresh product in color, flavor, texture and nutritive value.

VARIETY OF VEGETABLE:

The freezing and canning industries have known for some time that only certain varieties of vegetables can be successfully processed, and the importance of using selected varieties in the dehydration industry is equally great. Some vegetable varieties acquire a distinctly bitter flavor when dried, while others lose considerable color and flavor as a result of the combined blanching and drying process. Satisfactory types are usually well colored, possess characteristic flavors and are satisfactory in vitamin content. Weakly colored and flavored vegetables are unsatisfactory.

STAGE OF MATURITY:

After the proper varietal selections have been made, the next step is a consideration of the stage of maturity of these vegetables. Vegetables at their optimum stage of maturity should be used; immature vegetables are weak in color and flavor, and overmature vegetables are usually tough and woody.

HARVESTING:

Green vegetables to be used for dehydrating should preferably be harvested early or late in the day, to avoid heat and direct rays of the sun, and brought to the dehydrator as quickly as possible to avoid deterioration. As an example, experiments have shown that a high-grade spinach will lose much of its vitamin C (ascorbic acid) content within six hours after cutting. Green, leafy vegetables which have been harvested for several days will not give satisfactory dehydrated products. Newly harvested, mature white potatoes are higher in vitamin C than those which have been stored for several months; some varieties of sweet potatoes after storage for two to three months will darken when dehydrated. Comparable changes occur in other vegetables during storage.

If it is not possible to begin processing of succulent vegetables, such as peas, very shortly after harvesting, they may be placed in cool storage at about 40° F. or packed with crushed ice and held thus for 12 to 16 hours without serious deterioration.

DELAYS BETWEEN HARVESTING AND PROCESSING TEND TO LOWER THE QUALITY OF THE FINAL PRODUCT.

PREPARATION:

Freshly harvested vegetables must be properly prepared before going into the dehydrator. Such preparation includes washing, sorting, trimming, peeling, coring, slicing, dicing or shredding and blanching. These preparation steps should be carried out with suitable mechanical equipment free from contact with copper, galvanized iron or other metals which tend to destroy flavor, color, and vitamins. The wash water should be of potable quality, as cool as possible, and soft rather than hard.

The line, consisting of preparation machinery and conveyor belts, should be so arranged that the incoming fresh vegetables are carried through the several steps at an even rate of flow and the filled trays go into the dehydrator without unnecessary delay. If the prepared vegetables cannot be blanched immediately, they should be held under clean, cool, running water or in a 1 or 2% salt solution. In no case should the unblanched product be held more than three hours prior to dehydration.

Equipment must be arranged so as to be accessible in all parts in order that thorough cleaning with steam and hot water is possible. Insanitary conditions in and around the plant may lead to rejection of deliveries and possible seizure of the product or criminal prosecution under the Federal or State Pure Food Laws.

TRAYING:

Prepared vegetables are spread evenly on suitable trays and the amount of loading is particularly important. The general practice of overloading trays to increase the capacity of the dehydrator is inefficient. Heavy loading of trays retards the air-flow through the raw product, resulting in longer drying time and consequent loss of quality and yield. Careful study has shown that loads of 3/4 to 1-1/2 lbs. per square foot may be used, the lighter loads for leafy vegetables and the heavier loads for most root vegetables.

Metal or wood trays having bottoms made of #4 or #6 tinned hardware cloth are best, but all-wood trays are more often used owing to the general unavailability of metal. (Galvanized trays are not recommended for use with fruit). A two-man tray 3' x 6', or one-man trays 3' x 3' are ordinarily used. When the loaded trays are stacked one on top of the other, the open space between trays on the intake and discharge ends should be 2 inches to 2-1/2 inches, so that the air-flow over the vegetables is not greatly retarded.

BLANCHING:

All vegetables, with the exception of onions, should be properly steam blanched for varying lengths of time, depending on the vegetables used and the size of the pieces. The purpose of blanching is to inactivate enzymes believed to be responsible in part for undesirable changes in color, flavor, texture and loss of vitamins during drying and subsequent storage. This blanching, or partial precooking, also hastens in the rehydration or reconstitution of the dried products.

Blanching is ordinarily carried out in steam of sufficient flow to heat the product to 190° F. within one minute. Water blanching has been recommended for certain vegetables, but this procedure tends to remove considerable soluble solids, color and water-soluble vitamins. Blanching in hard water toughens the vegetables and soluble iron salts will discolor them.

The length of blanch for each individual vegetable is important. Under-blanching does not give the desired results, while over-blanching makes the product "mushy" and hard to dry. The vegetables should be subjected to direct contact with live steam, and the timing of blanching should not be started until the blancher temperature has reached 190° F. or higher.

DRYING:

The tunnel type dehydrator is especially designed for continuous operation. Where labor supply, legal restrictions, or other causes prevent such operations, the cabinet or batch dehydrator is more satisfactory. Using the cabinet type, it is possible to make two runs per day of many products, keeping a full working force only during a reasonable working period.

The spray and drum types of dehydrators give products in a powdery or flaky form. Such products are of value in some soup stocks, as condiments or for other uses where size of the piece is unimportant.

Vacuum dehydrators are in use to a very limited extent. They may operate continuously or as a batch process. Temperatures used extend below the freezing point of the material to be dried, up to perhaps as high as 115-120° F. Vacuum dehydrators require large amounts of metal in proportion to output of product, and they also require considerable auxiliary equipment, particularly in the form of vacuum pumps or steam ejectors.

From the economic standpoint, the selection of any type of dehydrator depends primarily upon:

(a) The cost of equipment and installation per unit of output.
(b) Operating cost per unit of output.

At present, the tunnel type of dehydrator is most generally used.

The time required to dry vegetables in a tunnel-type, hot-air dehydrator and the daily drying capacity of the same dehydrator are inseparably related, so that any change which affects the one will affect the other. Considerations of quality favor rapid drying. Conditions which bring about rapid drying will, other things being equal, also increase the drying capacity of the dehydrator; but paradoxically, a reduction in the drying load imposed on the unit may be the only feasible method of shortening the drying time.

Experimental work indicates that under conditions which take no account either of capacity or economy, blanched spinach may be dried in less than 1 hour, riced white potatoes in 2-1/2 hours, and blanched cabbage shreds in 2 hours. Practical drying times must be longer.

The factors which determine the practical drying time are: (1) design of dehydrator, (2) volume of air-flow, (3) maximum safe temperature, (4) proportion of recirculation of air, (5) rate of input of wet product (that is, dehydrator capacity), (6) weight or depth of moist product carried by unit of the trays, and (7) character of the product to be dried.

1. Design of Dehydrator

(a) In general, rapid drying is favored by a dehydrator which assures intimate contact of the rapidly moving drying air with the product, and eliminates useless short-circuiting of air.

(b) Rapid drying at reasonable capacity is favored by moving the air through the tunnel in the opposite direction to the flow of the product ("counter-current"), or introducing hot air at both ends of the tunnel and exhausting the cool, moist air near the center.

(c) Rapid drying is favored by insulating the tunnel against loss of heat, and by eliminating air leakage.

(d) Rapid drying is favored by moving the air at high velocity over the moist product. This velocity should be at least 800 linear feet per minute, and it may, with advantage, be 1,000 or even 1,200 linear feet per minute, at least in the wet end of the tunnel. After one-half to two-thirds of the moisture has been removed from the material, air velocity has little effect on the rate of drying.

(e) Rapid drying is favored by the use of drying trays with metallic perforated or mesh bottoms, which transfer heat by conduction to the moist material; and by using any arrangement which causes a part or all of the drying air to pass through the layer of moist material.

2. Volume of Air-Flow

Entirely separate from the effect referred to above a high total volume of air-flow favors the combination of rapid drying with high drying capacity.

3. Maximum Safe Temperature

Rapid drying is favored if the incoming air is heated to the highest temperature that is safe to use on the product in question. This allowable air temperature is generally somewhat higher for the moist product than for the dried, because the moist product stays relatively cool while its moisture is evaporating rapidly.

4. Proportion of Recirculation of Air

(a) If a part of the air exhausted from the cool end of a tunnel is returned, mixed with the incoming fresh air, and reheated, the air in the tunnel becomes more moist; drying time becomes longer, but a substantial saving of heat results.

(b) A high percentage of recirculation is common in fruit drying tunnels, partly to prevent the occurrence of "case-hardening", a condition which develops when dehydration is attempted at too high a temperature and too low a relative humidity. It consists in the formation of a horny shell which retards both dehydration and rehydration. This phenomenon is rarely experienced in the dehydration of blanched vegetable slices, strips, and cubes of the usual dimensions, and recirculation becomes almost entirely a matter of compromise between heat economy and tunnel capacity or drying time.

Note: Factors 2, 3, and 4 - Volume of air-flow temperature, and proportion of recirculation - taken together, determine the theoretical maximum drying capacity of the dehydrator. Actual drying performance must always be less than this theoretical maximum, and may be only a small fraction of it.

5. Rate of Input of Wet Product

(a) Drying at the rate referred to in paragraph 1. may be realized in a tunnel dehydrator only by operating the equipment in such a manner that the air passing through the tunnel does not cool perceptibly, and is low in relative humidity throughout the tunnel. These conditions can be attained in ordinary tunnel dehydrators only by diminishing materially the weight of moisture evaporated into the given volume of circulating air;

that is, by diminishing the evaporative load on the tunnel. The evaporative load may only be decreased by diminishing the weight of moist product charged into the tunnel per hour -- either by decreasing the load of product per square foot of tray surface while decreasing in a smaller proportion the length of time a single truck is held in the tunnel, or if the tray loading is maintained unchanged, by diminishing the number of trucks in the tunnel at once. The latter method, carried to the limit, leaves only a single truck, and the product is dried as a batch. Such a unit is known as a cabinet dehydrator. If a cabinet dehydrator is operated in this way to attain maximum drying rate, the cost of heat is excessive, while if measures are taken to conserve heat -- for example, by recirculation -- drying time lengthens toward that normally required in a tunnel.

(b) It should be noted that if the air-flow must be interrupted whenever a fresh truck is put into the tunnel, drying substantially stops in all of the trucks while the tunnel remains open. If this changing of trucks takes place at short intervals of time, the equipment loses a perceptible part of its rated drying capacity. For example, if effective drying stops for 2 minutes out of every 15, drying capacity is almost 10 percent less than if the shutdown is for only 2 minutes out of every 45. The length of time trucks must be held in the tunnel increases proportionally. The improvement in drying time which may be expected to result from light tray-loading is, therefore, partly offset by this factor of increased shutdown time.

6. Weight or Depth of Moist Product Carried by Unit Area of Trays

Rapid drying is favored by relatively light tray loading. There is a fairly definite load per square foot, characteristic for each type of material, which will tend to produce the maximum drying performance of the dehydrator. However, although capacity decreases only slightly at loadings considerably above or below this critical loading, drying time is substantially longer at the heavier loadings and substantially shorter at the lighter ones. It is usually desirable, therefore, to use a tray-loading somewhat lighter than that which would give the absolute maximum of output.

Note: The main advantage of a reasonably long tunnel, in vegetable dehydration, is that it allows trays to be loaded lightly, thus helping to increase the rate of drying, without unduly decreasing the capacity of the tunnel. Too long a tunnel, on the other hand, is difficult to control, and is expensive to build, maintain and operate. Practical commercial tunnels compromise between the extremes, and range from 30 to 55 feet long overall; the actual length occupied by trucks is usually between 20 and 40 feet.

7. Character of the Product to be Dried

(a) Regardless of the amount of air and heat furnished, if the moisture is difficult to remove because of physical structure, high sugar content, or other reasons, the drying cannot be rapid or the drying capacity high. Experimental determination of drying rate under known conditions is the only way to evaluate the effect of these differences.

(b) Pieces of thin cross-section dry more rapidly than thick ones.

(c) Pieces which give a porous layer on the tray -- potato or cabbage shreds, or strongly curling carrot slices -- dry faster than pieces which adhere into a single thick layer, like non-curling potato slices.

(d) "Mush" caused by bruising, careless handling, or over-blanching dries very slowly.

8. Sources of Heat for Drying

(a) Where natural gas is an abundant and economical fuel, the air supply to a dehydrator may be most conveniently heated by direct combustion of the gas in the circulating air itself. Under proper safeguards, some grades of fuel oil may be similarly burned directly in the circulating air without damage to the product. Low-grade fuel oils, such as crude oil, or coal, or wood, must either be burned in a separate furnace, from which heat is transferred to the circulating air through a system of sheet metal flues, or used to generate steam in a suitable boiler. In the latter case, heat is transferred to the circulating air through an appropriate steam radiator installation.

(b) When gas or oil is burned directly in the drying air, substantially all of the heating value of the fuel is made available to the dehydration process. If the heat transfer is indirect, on the other hand, whether through a flue system, or through the steam-boiler-radiator combination, not more than 50-75% of the heating value of the fuel will be available to the dehydrator.

(c) The amount of heat which must be supplied to the circulating air will generally range between 2,000 and 5,000 B.t.u. per pound of water evaporated. The actual heat usage in any specific case will depend in a complex manner on many of the factors named in the foregoing discussion. Many commercial tunnel dehydrators operate at a heat input of approximately 3,000 B.t.u. per pound of evaporation.

(d) If heat is supplied through a steam boiler, the boiler capacity required will be roughly 6 to 10 boiler horsepower for each ton of vegetables to be dried per 24 hours. The boiler capacity required to serve a continuous dehydrator, such as a tunnel, will ordinarily be less than that required by a group of batch dehydrators of the same daily drying capacity.

Summary

Commercial dehydration makes practical compromises between many of the foregoing factors. Local conditions will affect the relative importance given to one or the other. The actual drying time, even for the most easily dehydrated products is rarely less than 4 hours and is more usually 5 to 6 hours. Drying times of 6 to 8 hours are frequently encountered in practice. A time as long as 12 hours is unnecessary for any common vegetable, in slices, shreds, or cubes of the usual dimensions, if the final moisture content need not be reduced much below 5 to 7 percent. The shorter the drying time for a given product, in general, the higher will be the dehydration cost per pound of product for heat, power, and some elements of labor, but if the short drying time is accompanied by increased plant output, fixed charges per pound of product will usually decrease, partly or wholly offsetting the higher operating cost.

PACKAGING

Dehydrated vegetables must be packed in suitable containers which are moisture-proof, moisture-vapor-proof, and insect-proof. Precautions should be taken that the product is not insect-infested before being put in the containers. For best results, the packaging should be done within a reasonable time in a room with low relative humidity, free from dust, and separate from the operating part of the plant. Five-gallon, friction-top tin cans which are spot soldered are ordinarily used as containers for dried vegetables. Moisture-proof paper containers are being developed for the packaging of these products.

In order to prevent insect-infestation, and especially the deposition of insect eggs on the dried products, the packing room and the packages must be kept scrupulously clean, and fumigated if necessary. As an additional precaution, the products may be heated to 135° F. for a few minutes immediately before packing. All packages should be given the same treatment, or otherwise fumigated immediately before filling. Packages must be closed directly after filling.

Army specifications require that certain dehydrated vegetables must be packed under an inert gas, such as carbon dioxide or nitrogen.

Nitrogen is preferable for green vegetables. These gases can be obtained in cylinders and the amounts of gas needed drawn off through reducing valves and tubing. After filling the container, the gas flow pipe is inserted to the bottom and the lid adjusted as completely as possible. After 30 seconds, the tube is slowly removed and the lid pressed on and spot soldered. Two five-gallon cans of dried vegetables are packed together in a light-weight box for shipping.

A more accurate method of introducing gas into the cans is by means of a vacuum bell or other evacuated chamber in which the air content of the container is replaced with either carbon dioxide or nitrogen. Another method is to thrust the gas flow pipe to the bottom of the loosely-covered 5-gallon can filled with dehydrated vegetables. One cubic foot of the gas (approximately 50 percent in excess of 5 gallons) is allowed to pass through the gas flow pipe. The gas should pass through a recording gas meter which can be either of the dry or wet type. The most convenient meter has a sweep hand showing one cubic foot per revolution. This technique insures a thorough replacement of the air to below 2 percent of oxygen. The lids of the cans are then immediately put in place and spot soldered.

It should be pointed out that where specifications call for hermetically-sealed containers, friction top cans with or without spot soldering, will not be considered as "hermetically-sealed."

The packaged material should be stored in a cool, dry place. The lower the storage temperature, the longer the life of the product.

METHOD OF DETERMINING MOISTURE IN DRIED VEGETABLES

For factory control work, the most satisfactory method of determining moisture is by a slight modification of the so-called Bidwell-Sterling technique described in the "Method of Analyses of the Association of Official Agricultural Chemists." For this, one will need:

Bidwell-Sterling moisture apparatus

1 small scale - a diabetic scale will be sufficiently accurate
1 hand-operated meat grinder
1 electric stove

The Bidwell-Sterling apparatus and "diabetic" scale can be purchased from any large chemical supply house.

The method of determination is as follows:

Grind a representative sample in the meat grinder using the finest knife. Introduce 25-30 grams (accurately weighed) of the ground sample into the flask of the distilling apparatus.

Add about 120 c.c. of toluene and connect the apparatus. Fill the receiving tube with toluene by pouring through the top of the condenser. Bring to a boil and distill slowly about 2 drops per second for 20 minutes; then increase the rate of distillation to 4 drops per second for 10 more minutes. Stop the boiling and wash down the condenser by pouring toluene in at the top. If any water remains in the condenser, remove it by brushing down with a tube brush attached to a copper wire and saturated with toluene, washing down the condenser at the same time. Allow the receiving tube to come to room temperature. If any drops adhere to the sides of the tube, force them down by means of a rubber band wrapped around a copper wire. Read the volume of water (in cubic centimeters) which will be the bottom layer in the receiving tube. Calculate the percentage of water in the sample by the simple formula:

$$\frac{\text{cubic centimeters of water in receiving tube}}{\text{weight of sample taken}} \times 100 = \%\ \text{water}$$

Inasmuch as toluene vapors are toxic when inhaled to any extent and inflammable, the determination should be carried out in a well ventilated room.

If further detailed information is desired, inquiries should be addressed to:

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